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Stock Assessment of Arctic Grayling in Mineral Lake Outlet, 1990

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ABSTRACT

Arctic grayling *Thymallus arcticus* were captured by beach seine at Mineral Lake outlet during spawning from 11 through 14 May 1990. A mark-recapture experiment was conducted over a short period of time to reduce problems of closure encountered in a 1988 study. Estimates of age and size composition following two years of special regulations on the fishery were calculated using adjustments based on relative capture probabilities of 0.06 for smaller fish (199 to 287 mm fork length) and 0.30 for those larger than 287 mm fork length. Age and size composition estimates from 1988 and 1990 indicated slight reductions in older or larger Arctic grayling. A higher proportion of age 6 grayling found in 1990 may have resulted from the concurrent restrictive harvest regulation, or cohort strength. Length and age at maturity was re-determined and supported earlier findings that maturity was achieved in 50 percent of sampled grayling at 236 mm fork length, or age 4. Growth of Arctic grayling captured at Mineral Lake outlet was modeled using the Von Bertalanffy growth equation for data collected in 1988 and 1990, combined.

KEY WORDS: Arctic grayling, *Thymallus arcticus*, Mineral Lake outlet, age composition, size composition, maturity, Relative Stock Density, spawning stock, growth.

INTRODUCTION

Mineral Lake outlet has and continues to offer one of the few road accessible fisheries in Alaska that focuses upon a discrete spawning population of Arctic grayling, *Thymallus arcticus*. The outlet is a spawning area for fish that overwinter downstream in the Little Tok, Tok, and Tanana rivers and those resident in the Little Tok River drainage during summer (Tack 1974). It flows approximately 3.2 km from Mineral Lake downstream to the confluence with the Little Tok River, approximately 64 km south of Tok along the Glenn Highway (Tok Cut-Off; Figure 1).

This spawning population has offered a small, but popular spring fishery for the residents of Tok and Mentasta since the early 1960's (Tack 1974; Pearse pers. comm.[1]). Existing harvest and effort data is limited to one four-day creel survey conducted during May, 1973. The 45 anglers interviewed harvested 170 Arctic grayling in 141 hours, for a harvest rate of 1.21 Arctic grayling per hour (Ridder 1989a).

In 1987, local concern was voiced over a perceived decline in numbers and size composition of Arctic grayling in the recreational harvest. Coupled with expectations of increased angling pressure from local population expansion, and subsequent action by the Alaska Board of Fisheries, the outlet fishery was included in special regulations for Arctic grayling in the Tanana River drainage in 1988. These regulations included limiting the fishery to catch-and-release until the first Saturday in June, a 305 mm total length limit, and a no bait restriction.

Historically, studies that were conducted between 1969 and 1973 at the outlet described spawning behavior and migrational timing to determine a suitable site for an egg-take (Roguski and Tack 1970; Tack 1971, 1972, 1973). Stock assessment data were limited to one year of data on age composition, age at maturity, and growth. Spring sampling resumed at Mineral Lake outlet in 1988 (Ridder 1989a) to characterize the spawning run, particularly abundance, age and size composition, and, sex and maturity. Estimation of abundance of the spawning stock was restricted to males in one pool during one 24-hour period. Problems with ensuring geographic closure and sampling selectivity in other locations, and longer time periods precluded estimates of the whole spawning stock (Ridder 1989a). Likewise, estimates of sex ratios were precluded by a potential sampling bias in favor of males. Size and age at maturity estimates were found to be lower than is the case for other spawning stocks in the Tanana drainage.

Following two years of special regulation, information on the age and size composition was desired to investigate whether regulation changes had grossly affected the Mineral Lake spawning stock. Field investigations in 1990 were conducted over a short time interval to increase the likelihood of population closure. The study objectives for 1990 were to estimate:

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[1] Pearse, G. A. Personal communication. Alaska Department of Fish and Game, Sport Fish Division, 1300 College Road, Fairbanks, Alaska 99701.

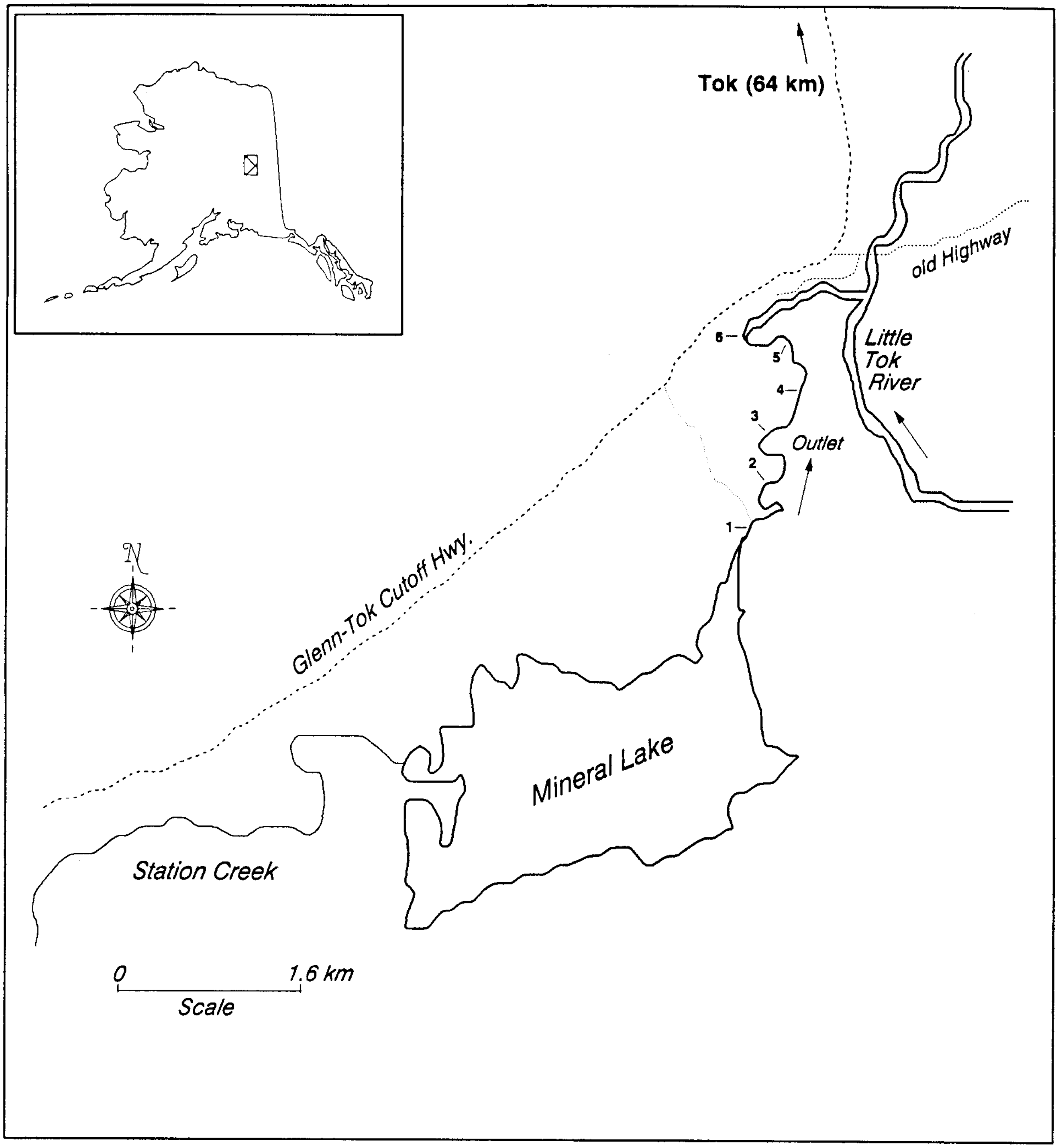

Figure 1. Map of Mineral Lake outlet study area.

1) the relative probability of capture by size class of Arctic grayling in the spawning run at Mineral Lake outlet; and,

2) the age and size composition of Arctic grayling in the spawning run at Mineral Lake outlet.

In addition, information on age-at-maturity, size-at-maturity, and growth were obtained.

METHODS

In 1988, sampling with beach seines (6.4 mm mesh bag seine; 23 m × 1.8 m) was found to be efficient, but gear efficiency was sometimes reduced at particular sampling locations. The long duration of sampling activity in that year (10 through 25 May; Ridder 1989a) may have contributed to violation of assumptions pertinent to mark-recapture abundance estimation. Sampling in 1990 occurred over three days: 11 through 12 May, and 14 May. Sampling occurred at the upstream end of the outlet because this site offered easy access, the best hydrologic conditions for beach seining, and contained large numbers of Arctic grayling (Figure 1, site 1; Ridder 1989a). Fish captured from repetitive seine hauls were placed in a holding pen (1.5 m × 1.5 m × 1.5 m) located above the seining location, and were held for 0.5 to 1 hour prior to data collection. All Arctic grayling greater than 199 mm fork length (FL) were tagged with Floy FD-67 anchor tags and given a left-ventral fin clip. The marking event was completed after the required sample size for age composition (600 fish) was attained.

Estimation of Age and Size Composition

Fork lengths of all captured Arctic grayling were recorded to the nearest 1 mm FL. A minimum of two scales was collected from the preferred zone[2] on all initial captures greater than 149 mm FL. Scales were later cleaned in a hot solution of detergent, and the two best scales (from each fish) were mounted on gummed cards and pressed. Scale impressions were made on 20 mil acetate film using a Carver press at 7,000 kg/cm^2 heated to 97°C. Ages were estimated from a single count of scale annuli using a microfiche reader.

The use of mark-recapture techniques allowed detection and adjustment for sampling biases introduced by fishing gear(s) using relative probabilities of capture. Difficulties in achieving unbiased estimates of abundance in 1988 may have been due to the longer duration of mark-recapture sampling, leading to closure problems. The use of a short sampling period should have more adequately "closed" the sampled population for the purpose of estimating age and size composition of the fishable stock at Mineral Lake outlet. Shortening the sampling period may increase the likelihood that the entire outlet stock is behaving similarly, i.e. immigrating or emigrating at equal probabilities. This would reduce risks of age or size specific behavior, i.e. spawner

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[2] The preferred zone for Arctic grayling is centered approximately six scale rows above the lateral line just posterior to the insertion of the dorsal fin.

emigration following high water temperatures. Although abundance estimation was not an objective for 1990 because of anticipated bias, corrections to sampled age and size composition by relative capture probabilities was undertaken following tests of assumptions germane to abundance estimates. This method of adjustment, using "relative" probability of capture, is analogous to the "actual" probability of capture used to estimate abundance, but the mark-recapture experiment is inherently biased. Use of a closed model to accurately estimate abundance in a mark-recapture experiment (Seber 1982) assumes the following:

1) the population in the study area must be closed;

2) all Arctic grayling have the same probability of capture during the first sample or in the second sample or marked and unmarked Arctic grayling mix randomly between first and second samples;

3) marking of Arctic grayling does not affect their probability of capture in the second sample;

4) Arctic grayling do not lose their mark between sampling events; and,

5) all marked Arctic grayling are reported when recovered in the second sample.

Assumption 1 was not thoroughly tested, but the shortened sampling period was thought to have lessened risks associated with closure for the sole purpose of estimating age and size composition. The extent of closure necessary for abundance estimation was thought to be at risk, based upon high levels of migration activity by Arctic grayling populations following spring break-up (Tack 1980). Assumptions 2 and 3 were tested with two Kolmogorov-Smirnov two-sample tests. The first test compared cumulative length frequency distributions of marked Arctic grayling with that of recaptured Arctic grayling. The second test compared distributions of fish captured in the first (mark) and second (recapture) events. The results of these tests determined the methods used to alleviate bias (Appendix A1). Stratified size groupings were delineated by an iterative series of chi-square tests. The breakpoint between size strata was found where differences in capture probability, and significance of the departure (chi-square test statistic) was maximized.

To compensate for bias, recapture to mark ratios were used to adjust for differential relative capture probability by size of fish:

$$\hat{\rho}_l = \frac{RECAP_l}{MARK_l} \qquad (1)$$

where: $\hat{\rho}_l$ = the capture probability of Arctic grayling in size class l, regardless of age k;

$RECAP_l$ = the number of recaptures of Arctic grayling in size class l; and,

$MARK_l$ = the number of marked Arctic grayling in size class l.

From the ratio of the largest capture probability to the capture probability in size class l, an adjustment to the number sampled at age k that were also of size class l was estimated (ignoring the hat symbols of ρ):

$$\hat{A}_l = \frac{\rho_L}{\rho_l} \tag{2}$$

where: $\hat{A}_l$ = the adjustment factor for all Arctic grayling of size class l, regardless of age class k; and,
$\rho_L = \max(\rho_l)$, l = 1, 2, ..., m size classes.

The adjustment factor was multiplied by the number of Arctic grayling sampled at age k that were also in size class l:

$$\hat{x}_{kl} = \hat{A}_l \, n_{kl} \tag{3}$$

where: $\hat{x}_{kl}$ = the adjusted number of Arctic grayling of age k that are also in size class l; and,
n_{kl} = the actual number of Arctic grayling sampled that are age k and also in size class l.

The proportion of Arctic grayling that are age k then re-evaluated to:

$$\hat{p}_k = \frac{\sum_{l=1}^{m} \hat{x}_{kl}}{\sum_{k=1}^{o} \sum_{l=1}^{m} \hat{x}_{kl}} = \frac{\hat{x}_{k.}}{\hat{x}_{..}} \tag{4}$$

where: k = 1, 2, ..., o age classes; and,
l = 1, 2, ..., m size classes.

The variances of these adjusted proportions were estimated by bootstrapping (Efron 1982) recapture-to-mark ratios. In this instance, the capture histories of all fish handled were sampled 1,000 times. Each time, a sample size equal to the number of fish was drawn with replacement, and the recapture-to-mark ratio was computed. The distribution of 1,000 recapture-to-mark ratios was used to estimate the variance. Steps used in a generalized bootstrapping procedure include:

1) generate a pseudorandom number from a uniform distribution (between 0 and 1);

2) sample capture history of fish number "random number" × "total number of fish" + 1;

3) repeat 1 and 2 until a sample of "total number of fish" is taken;

4) generate parameter estimate from randomly sampled capture histories;

5) repeat 1 through 4 for 1,000 iterations; and,

6) calculate mean and variance of 1,000 iterations of parameter estimate.

Size composition of the stock present at Mineral Lake outlet at the time of sampling was described using the Relative Stock Densities (RSD) of Gabelhouse (1984). The RSD categories for Arctic grayling are: "stock" (150 to 269 mm FL); "quality" (270 to 339 mm FL); "preferred" (340 to 449 mm FL); "memorable" (450 to 559 mm FL); and, "trophy" (560 mm FL and larger). To estimate the proportion of fish in each RSD category, the adjustment factors used to estimate age composition were also used to adjust biased RSD[3] estimates. Adjustment is accomplished by replacing the number sampled at age k that were also in size class l (n_{kl}) with the number sampled in RSD category k = 1, 2, ..., 5 that were also in size class l (equations 1 through 4). Variance was estimated in an identical fashion to variance of proportion at age, bootstrapping the recapture histories of all fish 1,000 times.

Sex and Maturity

Since sampling was conducted during spawning of Arctic grayling, sex and maturity were readily determined by either sexual dimorphism or the presence of milt or eggs. Dimorphism is evident in differences in length of the dorsal fin of fish greater than 350 mm FL. The dorsal fin of large males extends past the adipose fin, but is noticeably shorter in females (Wojcik 1955). Dimorphism is also evident in differences in the length of the pelvic fins (males have longer pelvic fins than females (Bishop 1967). Females also exhibit a swollen vent during the spawning period and the abdomen may be flaccid (spawned out) or full (ripe) (Ridder 1989b). Sex ratios were presented in the 1988 study as the ratio of the number of males to females when initially captured (Ridder 1989a). Only one female Arctic grayling was recaptured, so adjustments using sex-based capture probabilities was not possible. The percent of mature Arctic grayling was recorded by length class and by age group. To estimate the age and length at which 50% of the fish are mature (LM_{50} and AM_{50}, respectively), the age or length, number examined, and number mature were treated as the dosage, sample size, and response, respectively, in a probit analysis (Finney 1971). Using a procedure in the Statistical Analysis System (SAS) called "PROC PROBIT", maximum likelihood estimates of the parameters of the probit equation were calculated. This resulted in the estimates of the dosage (age or length) that apportioned the sample to 50% mature with 95% fiducial limits. Because growth characteristics

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[3] Because the mark-recapture experiment was relevant only to tagged fish, adjustments to RSD indices for the present study have been truncated to include fish greater than 199 mm FL.

of males and females are assumed to be similar, maturity estimates were obtained for combined sexes.

Growth

Information was collected to estimate growth parameters particular to Arctic grayling present at Mineral Lake outlet. Pooled size and age data collected during May 1988 (743 age and size pairs) and 1990 (588 age and size pairs) were merged and reduced to mean length at age (arithmetic mean) and their variances (based upon standard estimating equations). These data were fitted to the von Bertalanffy growth equation (Ricker 1975), in which three parameters were estimated for the sampled stock:

1) L_∞ is the length an average fish could attain if life and growth continued indefinitely (Ricker 1975);

2) K is the Brody growth coefficient, which is a dimensionless variate that regulates incremental growth;

3) t_0 represents the hypothetical age at which a fish would have zero length (Ricker 1975).

The parameter estimates were obtained from use of the Marquardt (1963) compromise within a nonlinear least square procedure. Input values for the parameters ranged from 350 to 700 mm FL by 50 mm increments for L_∞ ; from 0.0 to 0.4 by 0.01 for K and -2.0 to 2.0 by 0.5 for t_0. The model was fit initially 360 times, using all permutations of input variables. Secondarily, the best fitting combination of L_∞, K, and t_0 input parameters, as denoted by the smallest sum of squared deviations, were used as initial values for the iterative solution of the equation.

Age and Size Composition in 1988 and 1990

Age and size composition data collected in 1988 and again in 1990 were analyzed so that gross differences in the stock composition at Mineral Lake outlet could be observed. Because the 1988 study design included a wider geographic range of sampling effort (Ridder 1989a), data from sites not sampled in 1990 were removed from the 1988 data set (sites 2 through 6; Ridder 1989a). Mark-recapture data from 1988 was subjected to the same methods as the present study to detect and reduce bias introduced through sampling gears.

RESULTS

Stream temperatures ranged from a morning low of 5°C on 11 May, to 8°C, measured in the afternoon on 12 May. A total of 28 seine hauls yielded a total catch of 873 fish (all sizes of fish).

Capture Probabilities and Adjustment to Age and Size Compositions

Although this report emphasizes stock assessment at Mineral Lake outlet in 1990, data collected in 1988 was subjected to similar analysis and adjustment for comparison between years.

Analysis and Adjustments 1990:

A total of 510 Arctic grayling (≥ 200 mm FL) were captured at Mineral Lake outlet in the three days of sampling with beach seines. Catches during the marking event (11 through 12 May) included 389 Arctic grayling; during the recapture event (14 May), 181 Arctic grayling were examined yielding 60 recaptured fish. Statistical comparison of the cumulative length distributions (Figure 2A) of the marked and recaptured fish revealed a significant bias (DN = 0.38, P = <0.01; Kolmogorov-Smirnov Two-Sample test). This finding suggests that bias occurred in the second sampling event. A second statistical comparison of the cumulative length distributions of the first (marking) and second (capture) events (Figure 2B) also showed a significant bias (DN = 0.22, P = <0.01; Kolmogorov-Smirnov Two-Sample test). This test indicated that size composition varied significantly between sampling events. Test results indicated that size selectivity occurred in the second sampling event and, stratification by size groups with differing capture probability was needed to adjust age and size composition. The stratification breakpoint was chosen at 287 mm FL, where the differences in capture probability was maximal between mark and recapture samples. Capture probabilities for the two strata were 0.06 and 0.30, corresponding to the small (199 through 287 mm FL) and large fish (≥ 288 mm FL), respectively. Adjustments made to the age composition of Arctic grayling (≥ 200 mm FL) ranged from 3% to 8%, and overall, the adjustments redistributed 20% of the sample (Table 1). Size composition (Table 2) for the present study was adjusted for a bias of 19%. Age 4 Arctic grayling dominated the age composition (27%), and stock size Arctic grayling made up 63% of the sampled population.

Reanalysis and Adjustments 1988:

Re-analysis of information from the 1988 study, for comparison with the present study, was based on 151 Arctic grayling marked between 10 and 17 May, and 229 fish examined for marks between 18 and 25 May. Comparisons of the cumulative length distributions (Figure 3A) of the marked and recaptured Arctic grayling demonstrated no significant bias during the recapture event (DN = 0.25, P = 0.25; Kolmogorov-Smirnov Two-Sample test). The cumulative length distributions of the first (marking) and second (capture) events (Figure 3B) were significantly different (DN = 0.18, P = <0.01; Kolmogorov-Smirnov Two-Sample test). This test indicated that size composition varied significantly between sampling events. Combined results of these tests inferred size selectivity did not occur in the second sampling event, and that stratification was not needed for age and size composition estimates. Age composition for the 1988 study (Table 3) and size composition (Table 2) reflect age composition based upon the unbiased second sampling event.

A comparison of estimated age compositions (Figure 4) between 1988 and 1990 suggests a slight depression in relative abundance for Arctic grayling ages 4,

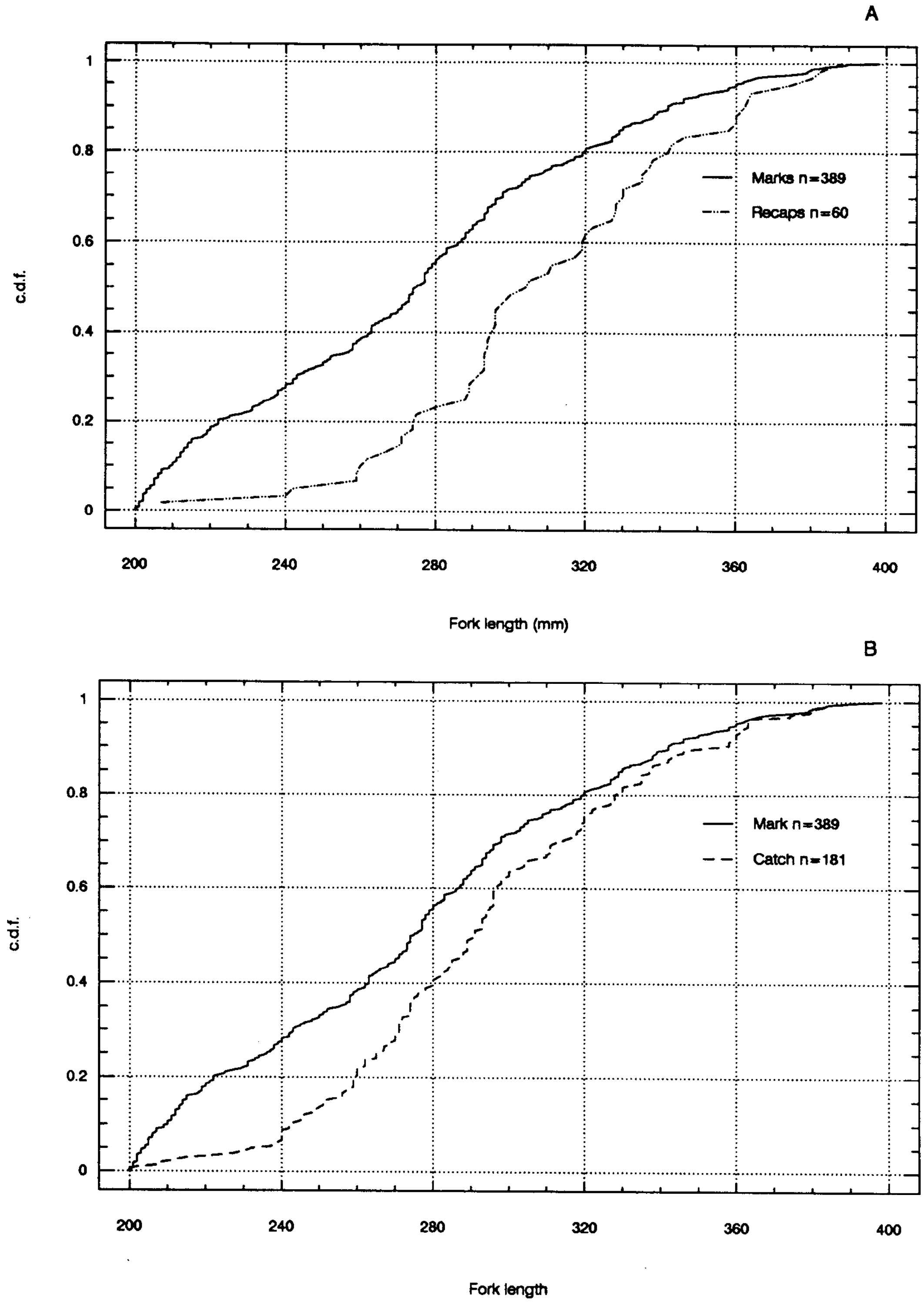

Figure 2. Cumulative distribution functions of lengths of Arctic grayling marked versus lengths of Arctic grayling recaptured (A) and versus lengths of Arctic grayling examined for marks (B) at Mineral Lake outlet, 11 through 14 May, 1990.

Table 1. Estimates of the sampled and adjusted[a] proportional contributions of each age class for Arctic grayling (≥ 200 mm FL) captured at Mineral Lake outlet 11 through 14 May, 1990.

	Sampled:			Adjusted:	
Age	n[b]	p[c]	SE[d]	p[e]	SE[f]
2	12	0.03	0.01	0.05	0.01
3	43	0.12	0.02	0.18	0.02
4	67	0.19	0.02	0.27	0.03
5	55	0.16	0.02	0.20	0.03
6	99	0.28	0.02	0.23	0.03
7	41	0.12	0.02	0.04	0.01
8	17	0.05	0.01	0.02	<0.01
9	12	0.03	0.01	<0.01	<0.01
10	5	0.01	<0.01	<0.01	<0.01
11	0	---	---	---	---
12	0	---	---	---	---
Total	351	1.00		1.00	

[a] Age composition is adjusted to compensate for length bias in the sample.
[b] n = sample size.
[c] p = proportion of sampled Arctic grayling.
[d] SE = standard error of the sampled proportion.
[e] p = adjusted proportion of Arctic grayling (≥ 200 mm) in stock.
[f] SE = standard error of the adjusted proportion.

Table 2. Summary of Relative Stock Density (RSD) indices for Arctic grayling (≥ 200 mm FL) captured at Mineral Lake outlet[a], 1988 and 1990.

	RSD Category[b]				
	Stock	Quality	Preferred	Memorable	Trophy
1988[c]					
Number sampled	111	95	23	0	0
Sample RSD	0.48	0.41	0.10	---	---
Standard Error	0.03	0.03	0.02	---	---
CV[d](%)	7	8	19	---	---
1990[e]					
Number sampled	172	174	41	0	0
RSD	0.44	0.45	0.11	---	---
Adjusted RSD[c]	0.63	0.35	0.02	---	---
Standard Error	0.03	0.03	<0.01	---	---
CV (%)	5	9	25	---	---

[a] Arctic grayling were sampled from several sites at Mineral Lake outlet in a 1988 mark-recapture study (Ridder 1989a) between 10 and 25 May. In 1990, a similar study ran 11 through 14 May at one of the sites sampled in the 1988 study.

[b] Minimum lengths for RSD categories are (Gabelhouse 1984):
- Stock - 150 mm FL;
- Quality - 270 mm FL;
- Preferred - 340 mm FL;
- Memorable - 450 mm FL; and,
- Trophy - 560 mm FL.

Because fish were only tagged down to 200 mm FL, these results are relevant to fish 200 mm FL and larger.

[c] Sampled RSD is reported here for the sampled section (Site #1, Ridder 1989a) that was sampled again in the 1990 sampling. Mark-recapture methods to remove sampling bias denoted the second sampling event (18 through 25 May) to be unbiased. Reported estimates of size composition are based upon this sampling period.

[d] CV = Coefficient of Variation, calculated as Standard Error divided by RSD, then multiplied by 100 percent.

[e] Sampled and Adjusted RSD's were based on the first sampling event in 1990, which was determined to be unbiased through mark-recapture bias removal methods. Adjusted RSD and Standard Error are determined from bootstrap methods (Efron 1982; Clark and Ridder 1988).

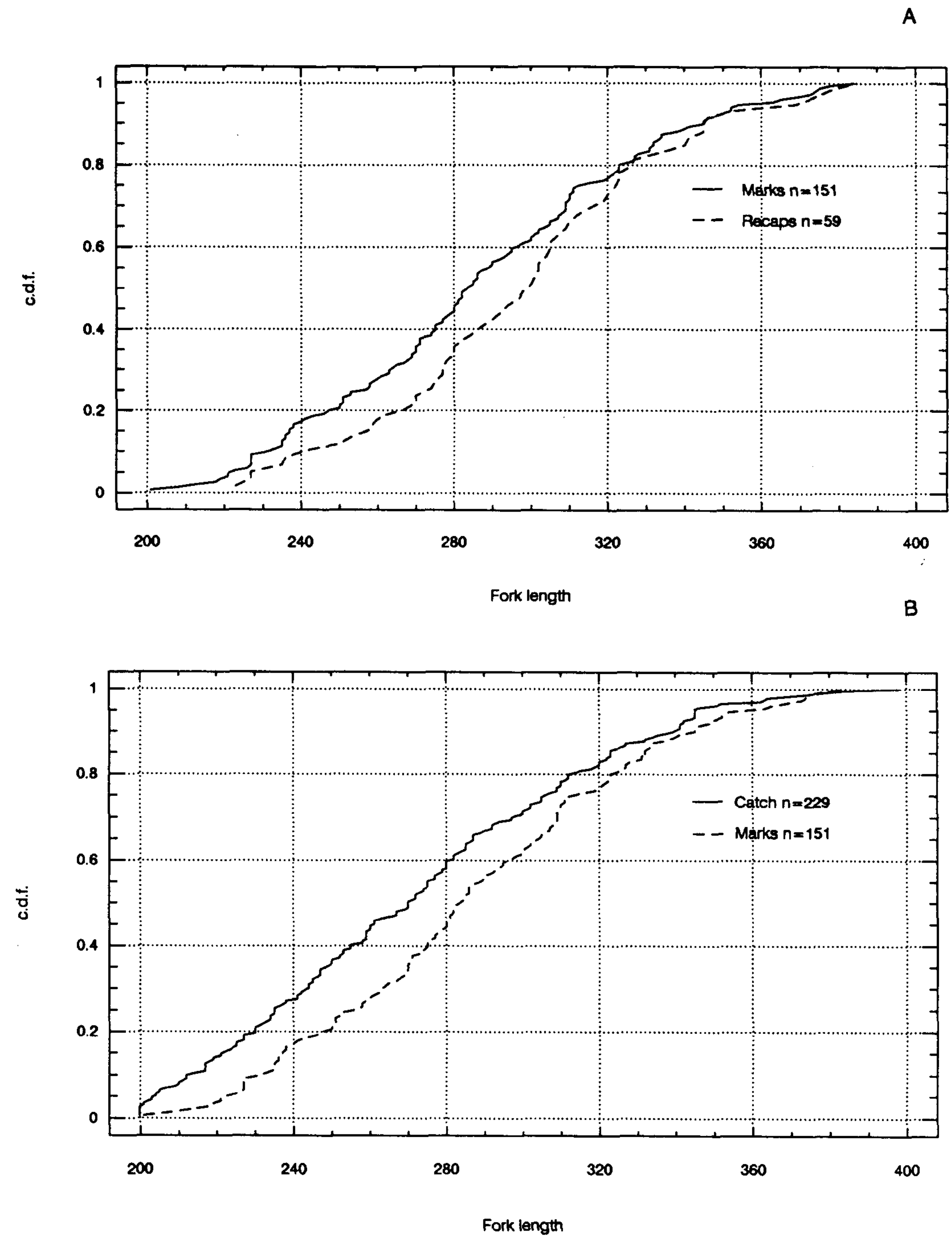

Figure 3. Cumulative distribution functions of lengths of Arctic grayling marked versus lengths of Arctic grayling recaptured (A) and versus lengths of Arctic grayling examined for marks (B) at Mineral Lake outlet, 10 through 25 May, 1988.

Table 3. Estimates of the sampled proportional contributions of each age class for Arctic grayling ($\geq$ 200 mm FL) captured at Mineral Lake outlet[a], 10 through 25 May, 1988.

	Sampled:		
Age	n[b]	p[c]	SE[d]
2	0	----	----
3	15	0.08	0.02
4	57	0.29	0.03
5	48	0.25	0.03
6	31	0.16	0.03
7	16	0.08	0.02
8	16	0.08	0.02
9	6	0.03	0.01
10	2	0.01	<0.01
11	1	<0.01	<0.01
12	1	<0.01	<0.01
Total	193	1.00	

[a] Data from the 1988 mark-recapture study at Mineral Lake outlet (Ridder 1989a) was truncated to include the same sampling areas as the 1990 field sampling for the purpose of comparison.

[b] n = sample size.

[c] p = proportion of sampled Arctic grayling.

[d] SE = standard error of the sample proportion.

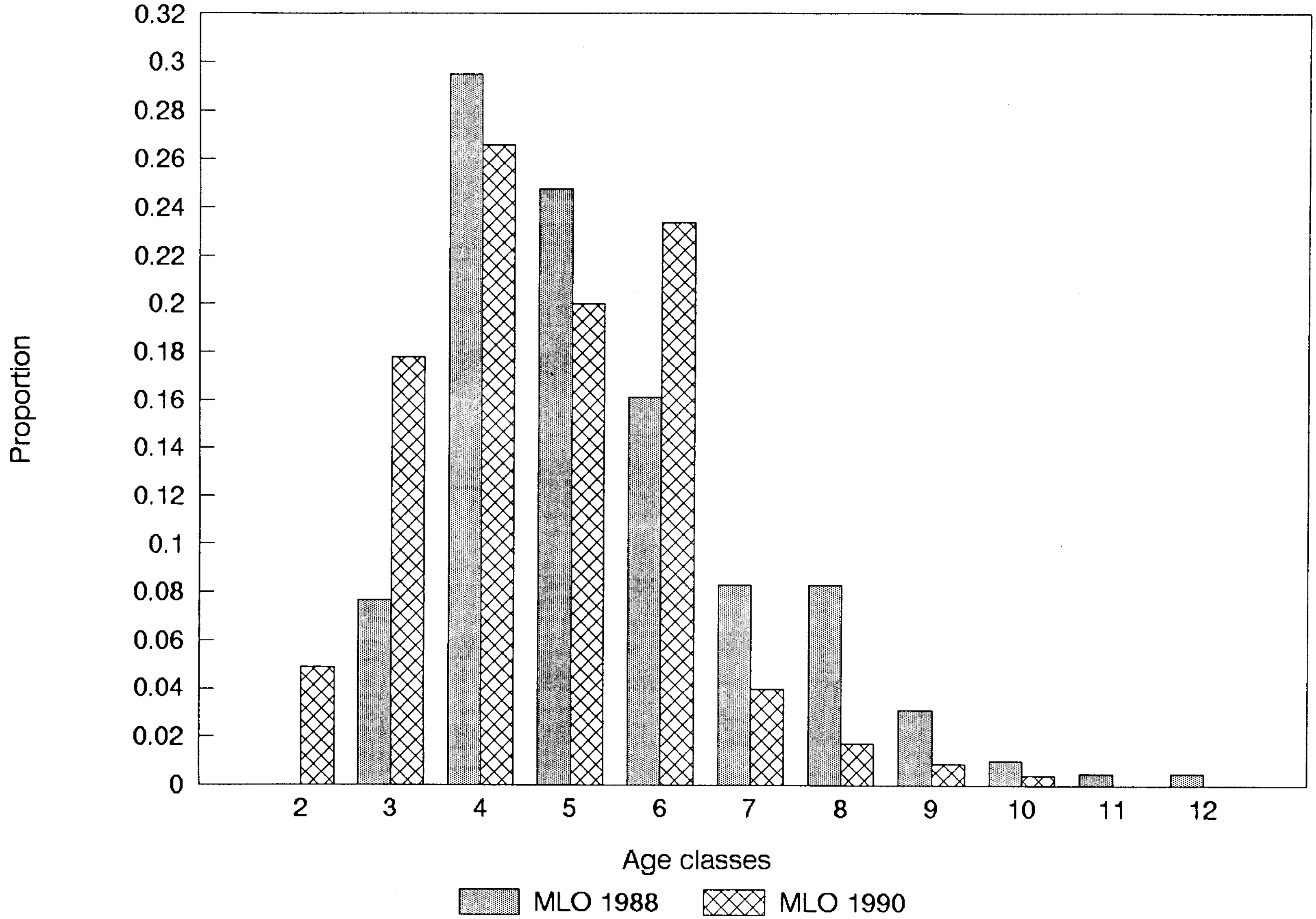

Figure 4. Estimated age compositions for Arctic grayling captured at Mineral Lake outlet in May 1988 and 1990.

5, and 7 through 10. The strength of the age 6 cohort has tracked well from its strength initially seen in 1988 sampling, at age 4. Size composition (Figure 5), shown as Relative Stock Densities (RSD), suggested a similar drop in the quality and preferred size categories, offset by a rise in the stock category.

Sex and Maturity

Using probit analysis, the length at which 50% of Arctic grayling sampled during 1990 showed evidence of maturity (LM_{50}) was 236 mm FL (Appendix A2). Fiducial limits corresponding to the 5 and 95 percentiles were 229 and 243 mm FL, respectively. The LM_{50} in the 1988 study was 237 mm FL, with fiducial limits of 203 to 260 mm FL (Ridder 1989a). Using the same probit procedures, the age at maturity (AM_{50}) was estimated in 1990 to be 4.0 years, with corresponding fiducial limits of 3.8 to 4.1 years. In 1988, the estimate was 4.3 years, but no fiducial limits could be calculated (Ridder 1989a). Unbiased sex ratios were not estimated because during mark-recapture sampling only one female and 59 males were recaptured, thereby precluding reliable adjustments.

Growth

Length at age information from 1988 and 1990 (Appendix A3) was used to successfully model growth of Arctic grayling at Mineral Lake outlet. All three parameters of the von Bertalanffy equation were estimated with sufficient precision (Appendix A4). The best fitting combination of input parameters L_∞, K, and t_0 were found to be 438 mm FL, 0.17, and -0.40, respectively.

DISCUSSION

In response to changes in regulations and concern for stock status at Mineral Lake outlet, investigations have characterized age and size composition in 1988, and again in 1990. These efforts were needed to monitor and manage the fishery, to examine regulation effectiveness, and, to enhance the stock assessment data base for Arctic grayling fisheries within the Tanana drainage.

The comparison of age and size compositions taken two years apart indicates slight changes resulting from a likely combination of natural population change and the effects of sport harvest. The separation of these components is outside the scope of this study. Exploitation of the Mineral Lake outlet spawning stock can be inferred as minimal if returns of tags by anglers is complete. Anglers returned four tags during the 1988 season and two in 1990. With 441 Arctic grayling tagged in 1988, and 509 tagged in 1990, this return represents an exploitation rate of only 0.6%. Ridder (1989a) reported 3.2% and 7.0% recapture rates by anglers at Caribou Creek, in 1987 and 1988, respectively. Tagging of prespawning Arctic grayling at the mouth of Shaw Creek in 1987 and 1988 gave angler recapture rates of 4.3% and 2.0%, respectively (Ridder 1989c).

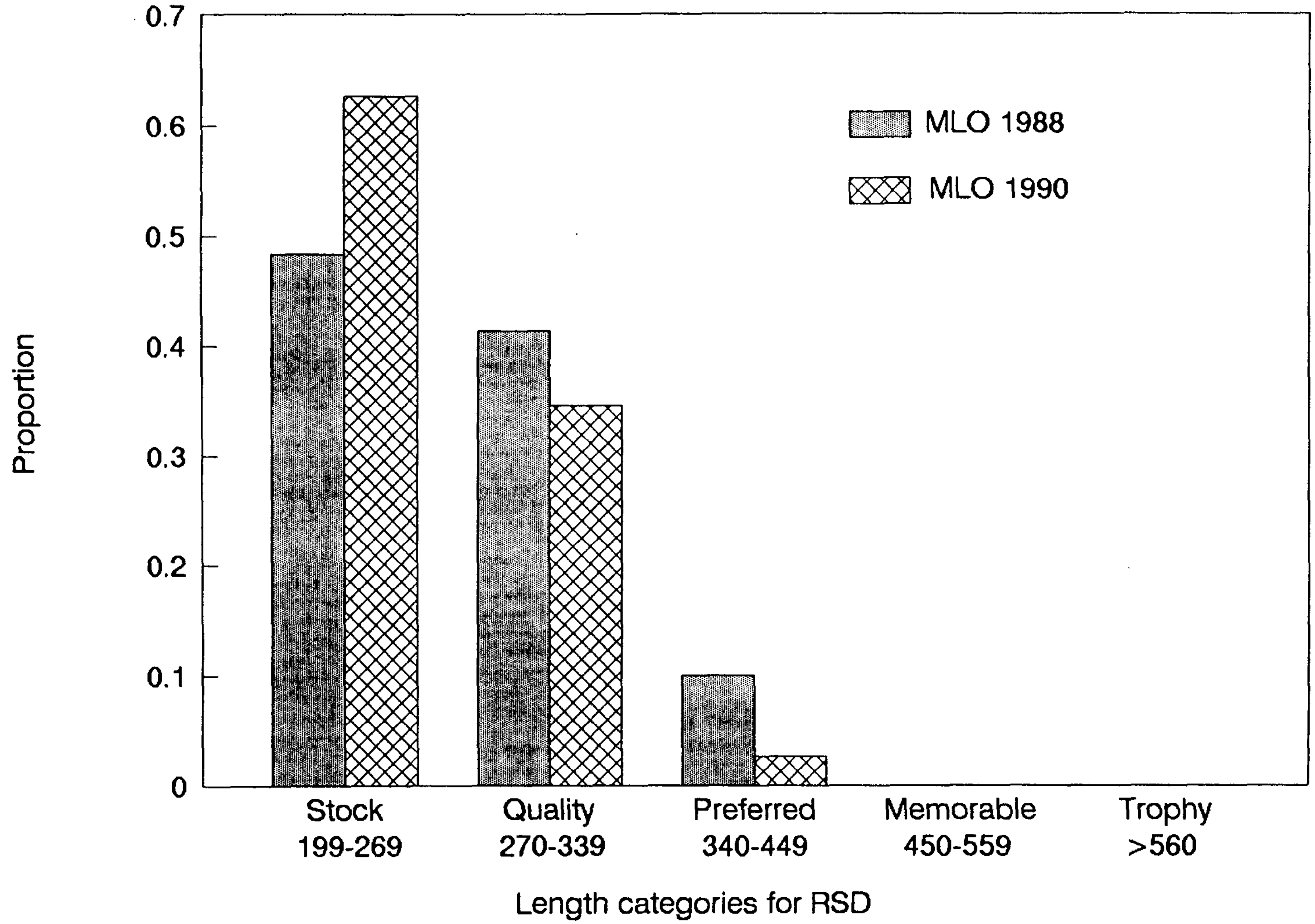

Figure 5. Relative Stock Densities for Arctic grayling captured at Mineral Lake outlet in May 1988 and 1990.

Although an abundance estimate was originally planned in 1988, the study had problems with geographic closure over the long duration of sampling. The 1990 study was conducted over a shorter time period, to reduce temporal elements of immigration and emigration. This study has shown that despite reducing the sampling "window", size dependant bias occurred, i.e. smaller fish were not equally represented in catches. Although sampling was shortened in duration, the reason for the bias we detected could have been associated with changes in behavior by size of fish. Increases in spawning activity and associated behaviors may have led to forced emigration of smaller fish prior to, or during the second sampling event. The sampling objectives were to target a period of homogeneous behavior, but it appears that we may have "bracketed" an inflection in behavior. It is likely that spring will remain a volatile period for the sampling of Arctic grayling populations, relative to the rapid succession and overlapping nature of migration(s) and spawning. Future timing and means of stock assessment will need to be carefully examined to avoid bias resulting from combinations of temporal and behavioral movements.

In other studies of Arctic grayling abundance and stock composition, mark-recapture experiments have included those fish greater than 149 mm FL (ages 3 and older). It would be advantageous to have estimates for Mineral Lake outlet using this same size range, for comparison with other stock assessment results. Because the LM_{50} for Arctic grayling sampled at Mineral Lake outlet was 236 mm FL and the targeted population is spawners, using 200 mm FL as a lower limit for tagging may be sufficient for assessment of stocks present at the spawning areas of Mineral Lake. However, future investigations should extend mark-recapture studies to Arctic grayling greater than 149 mm FL to estimate capture probabilities of subadults and "small" adults in spawning areas. These data could be used to determine if subadults were a strong component of spawning aggregations at these sites.

Information on the maturity and growth (Appendices A2 and A3) collected for Arctic grayling at Mineral Lake outlet will be an asset for present management decisions, and later as maturity and growth patterns are examined between different Tanana drainage populations. Because of the efficiency of beach seining at Mineral Lake outlet, periodic spring sampling may be an effective tool for monitoring and managing the spring fishery, especially as the different sampling biases are better understood.

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APPENDIX A

Appendix A1. Methodologies for alleviating bias due to gear selectivity by means of statistical inference.

Result of first K-S test[a]	Result of second K-S test[b]
Case I[c]	
Fail to reject H_0	Fail to reject H_0
Inferred cause: There is no size-selectivity during either sampling event.	
Case II[d]	
Fail to reject H_0	Reject H_0
Inferred cause: There is no size-selectivity during the second sampling event, but there is during the first sampling event	
Case III[e]	
Reject H_0	Fail to reject H_0
Inferred cause: There is size-selectivity during both sampling events.	
Case IV[f]	
Reject H_0	Reject H_0
Inferred cause: There is size-selectivity during the second sampling event; the status of size-selectivity during the first event is unknown.	

[a] The first K-S (Kolmogorov-Smirnov) test is on the lengths of fish marked during the first event versus the lengths of fish recaptured during the second event. H_0 for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish recaptured during the second event.

[b] The second K-S test is on the lengths of fish marked during the first event versus the lengths of fish captured during the second event. H_0 for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish sampled during the second event.

[c] Case I: Calculate one unstratified abundance estimate, and pool lengths and ages from both sampling event for size and age composition estimates.

[d] Case II: Calculate one unstratified abundance estimate, and only use lengths and ages from the second sampling event to estimate size and age composition.

[e] Case III: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Pool lengths and ages from both sampling events and adjust composition estimates for differential capture probabilities.

[f] Case IV: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Also calculate a single abundance estimate without stratification.
If stratified and unstratified estimates are dissimilar, discard unstratified estimate and use lengths and ages from second event and adjust these estimates for differential capture probabilities.
If stratified and unstratified estimates are similar, discard estimate with largest variance. Use lengths and ages from first sampling event to directly estimate size and age compositions.

Appendix A2. Estimates of age (years) and fork length (mm) at maturity for Arctic grayling (≥ 150 mm FL) collected from Mineral Lake outlet, 11 through 14 May 1990.

Age	Number Examined	Number Mature	Length Group	Number Examined	Number Mature
Raw data:					
1	3	0	150-159	19	0
			160-169	19	0
2	77	0	170-179	30	0
			180-189	39	0
3	98	7	190-199	27	0
			200-209	41	1
4	105	55	210-219	33	0
			220-229	19	2
5	74	61	230-239	26	17
			240-249	33	24
6	136	136	250-259	34	31
			260-269	36	34
7	49	49	270-279	61	61
			280-289	45	45
8	23	23	290-299	45	44
			300-309	21	21
9	14	14	310-319	24	24
			320-329	24	24
10	7	7	330-339	20	20
			340-349	14	14
11	2	2	350-359	11	11
			360-369	12	12
			370-379	5	5
			380-389	5	5
			390-399	2	2

Summary statistics[a]:

	Mean	Range		Mean	Range
AM_{01}[b]	2.6 yrs	2.3 to 2.7 yrs	LM_{01}[c]	203 mm	185 to 213 mm
AM_{50}	4.0 yrs	3.8 to 4.1 yrs	LM_{50}	236 mm	229 to 243 mm
AM_{99}	6.2 yrs	5.8 to 6.7 yrs	LM_{99}	275 mm	263 to 297 mm

[a] Summary statistics were calculated from probit analysis (Finney 1971).

[b] AM_X = xth percentile for age at maturity rounded to the nearest 0.1 year (ranges are the 95% fiducial limits).

[c] LM_X = xth percentile for fork length at maturity (ranges are the 95% fiducial limits).

Appendix A3. Estimates of the sampled proportional contributions of each age class and sampled mean fork length (mm) at age for all Arctic grayling handled at Mineral Lake outlet, 10 through 25 May 1988 and 11 through 14 May 1990[a].

	10-25 May 1988					11-14 May 1990				
Age	n[b]	p[c]	SE[d]	Mean[e]	SD[f]	n	p	SE	Mean[g]	SD
1	102	0.14	0.01	89	10	3	<0.01	<0.01	149	6
2	79	0.11	0.01	147	21	77	0.13	0.01	176	19
3	182	0.24	0.01	181	19	98	0.17	0.01	199	22
4	139	0.19	0.01	223	23	105	0.18	0.02	239	29
5	96	0.13	0.01	265	22	74	0.13	0.01	261	26
6	60	0.08	0.01	284	24	136	0.23	0.02	288	23
7	39	0.05	<0.01	311	28	49	0.08	0.01	319	23
8	29	0.04	<0.01	330	20	23	0.04	<0.01	344	26
9	10	0.01	<0.01	360	22	14	0.02	<0.01	354	21
10	4	<0.01	<0.01	353	16	7	0.01	<0.01	355	19
11	1	<0.01	<0.01	384	--	2	<0.01	<0.01	358	10
12	1	<0.01	<0.01	378	--	0	0.0	---	---	--
Total	742	1.0	---	214		588	1.0		228	

[a] All fish handled over the course of field investigations at Mineral Lake outlet in 1990 and 1988 (Ridder 1989) are included with no adjustments. Age and lengths of Arctic grayling not marked or tagged in the mark-recapture study too small to tag are included, and may influence estimates.

[b] n = sample size.

[c] p = proportion of sampled Arctic grayling.

[d] SE = standard error of the sample proportion.

[e] Mean = mean fork lengths for 1988, where n= 806 fish.

[f] SD = sample standard deviation.

[g] Mean = mean fork lengths for 1990, where n= 781 fish.

Appendix A4. Parameter estimates and standard errors of the von Bertalanffy growth model[a] for Arctic grayling from Mineral Lake outlet, 1988 and 1990 combined.

Parameter	Estimate	Standard Error
L_∞[b]	438	26
K[c]	0.17	0.02
t_0[d]	-0.40	0.16
$Corr(L_\infty, K)$[e]	-0.97	---
$Corr(L_\infty, t_0)$	-0.74	---
$Corr(K, t_0)$	0.86	---
Sample size	1,331	

[a] The form of the von Bertalanffy growth model (Ricker 1975) is as follows: $l_t = L_\infty (1 - exp(-K (t - t_0)))$. The parameters of this model were estimated with data collected during 1988 and 1990. This model was fitted to the data by nonlinear regression utilizing the Marquardt compromise (Marquardt 1963). The range of ages used to model growth was age 1 through age 11.

[b] L_∞ is the length a fish would achieve if it continued to live and grow indefinitely (Ricker 1975).

[c] K is a constant that determines the rate of increase of growth increments (Ricker 1975).

[d] t_0 represents the hypothetical age at wich a fish would have zero length (Ricker 1975).

[e] $Corr(x,y)$ is the correlation of parameter estimates x and y.